

Latex Beads Deposition on Porous Membrane for the Filtration of Colloid Particle

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Abstract

Colloidal particle, latex particle (1 μm), was deposited on the surface of the pores of the porous hollow-fiber membrane. The pore diameter of the membrane was 360 nm. Deposited structure of colloidal particle would demonstrate the novel filtration performance. Latex-beads (1 μm) containing solution was permeated through the porous hollow-fiber membrane to deposit Latex beads on the pore. The pressure loss of the Latex-beads (1 μm)-deposited membrane was dependent on the amount of deposited Latex beads. Permeation flux in permeating pure water through Latex-beads (1 μm)-deposited membrane was analyzed by cake resistance of Darcy's law, demonstrating that cake resistance increased with increasing the amount of Latex-beads (1 μm) deposited. Rejection performance of Latex-beads (1 μm)-deposited membrane in flowing colloidal particle (100 nm) was performed and the rejection phenomena was analyzed using pseudo-first order equation to obtain rejection coefficient. The rejection coefficient increased in the amount of Latex-beads (1 μm). Dispersion solution of soy insoluble protein was flown through the Latex-beads (1 μm) deposited membrane, representing that the deposited structure of Latex beads represented the novel microfiltration for food engineering.

Keywords

Colloid; Porous hollow-fiber Membrane; Latex Beads; Filtration; Soy Insoluble Protein

Introduction

In membrane separation, filtration is the separation method having the selectivity to colloidal particles and molecules based on sieving effect. The sieving effect is the size exclusion based on the size of colloidal particles and solutes. When molecules composed of membranes have the affinity to solutes and colloidal particles, the phenomena of adsorption and adhesion occur, resulting in the change of the permeation of the membrane.

Membrane filtration has been used for the processes such as salt slurry in water treatment (Kim & Bruggen, 2010), microorganism separation (Vasanth, et al., 2011), and food engineering (Tolkach & Kulozik, 2005). The pressure loss of these processes increases in flowing colloidal particle solution more than initial state. This is due to the formation of cake layer of filtrated compounds. Cake layer is formed by the filtered compounds on the membrane and in processing the filtration the depth and the porosity of the layer dynamically changes. The structure of cake layer during the filtration is controllable to set the appropriate structure to the target compounds, for instance, such as insoluble proteins and polysaccharides.

The filtered solutes and colloidal particles on the membrane form the deposited structure on the pore. This membrane performance is governed by the permeation resistance and sieving effect resulting from the structure of the porosity and the depth. To understand this kind of fouling phenomena, cake filtration model (Li, et al., 2011), concentration-polarized mode (Loginov, et al., 2013), gel-polarization model (Vennela, et al., 2011) have been proposed. Using these theories, protein filtration by the membrane has been discussed. During the filtration of colloidal particle, the target is dynamically filtered by the gradually-deposited colloidal particles. These manners of the formed layer on the membrane enable us to fabricate the appropriate function to the membrane.

In this study, the deposition of colloidal particle on the membrane was applied for the separation technique. To evaluate the filtered effect of deposited structure, Latex bead made of polystyrene was used. The amount of the deposited Latex beads (1 μm) on the

membrane was changed to analyze cake resistance of the deposited layer by Darcy's law. The deposited structure of the colloidal Latex beads (1 μm) was examined in permeation of smaller latex beads (100 nm). Soy insoluble protein solution was flown through Latex-beads-deposited membrane to perform the rejection performance for food engineering.

Table 1 Properties of porous hollow-fiber membrane	
Material [-]	High density polyethylene
Inner diameter [mm]	2.00
Outer diameter [mm]	3.00
Permeation flux [$\text{m}^3 \text{m}^{-2} \text{h}^{-1}$]*1	2.00
Effective length [mm]	25.0
Number of pore per surface area [m^{-2}]*2	7.5×10^{14}
Pore diameter [nm]	360

*1 Permeation flux was determined at 0.1 MPa of pressure loss at 25 $^{\circ}\text{C}$.

*2 Number of pore per surface area was determined by Hagen-Poiseuille equation.

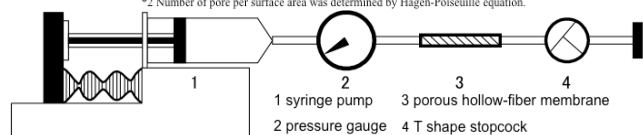


FIG. 1 EXPERIMENTAL APPARATUS OF PERMEATION MODE

Experimentals

Materials

Polyethylene porous hollow-fiber membrane (pore diameter: 360 nm, Asahi Kasei Chemicals Co., Ltd.) was used as a supporting membrane. The summarized properties of the used trunk membrane are summarized in Table 1. Pure water flux was calculated from Hagen-Poiseuille equation using water flow through the membrane.

Pure water flux ($\text{m}^3 \text{m}^{-2} \text{h}^{-1}$) = (volume of water flown through the membrane) / (surface area of hollow part of the membrane) (1)

Number of pore per surface was calculated as follows, with the assumption that the pore of the trunk membrane is cylindrical,

$$r^2 \pi L n = \text{pore volume over trunk membrane} \quad (2)$$

where r , L , and n are the pore radius, membrane thickness, and the pore number of the trunk membrane, respectively. The syringe pump (S33120) used was purchased from Atom Medical Corporation. Pressure gauge was obtained from Nagano Keiki Co. Latex beads (100 nm and 1.0 μm) made of polystyrene was purchased from Micromer®plain. Soy insoluble protein (FujiPro F) was obtained from Fuji Seiyu Co., Ltd., Japan.

Formation of Colloid Particle Deposition on the Trunk Membrane

The experimental apparatus composed of porous hollow-fiber membrane, pressure gauge, syringe

pump and T shape stopcock, as shown in Figure 1. The flow through the membrane was controllable with dead end. Latex bead-containing solution (1 μm , 200 mg/L) was fed through the porous hollow-fiber membrane using the syringe pump at 50 mL/h. Latex beads were rejected by the membrane due to the sieving effect, because the particle size of latex beads was larger than that of the membrane. Rejected latex beads were deposited on the membrane to perform filtration. The amount of deposited latex was changed by the permeation time at 6, 30, and 60 min. The pressure loss during flowing was determined at every 3 min. The concentration of colloid in the effluent was determined by the absorbance at 600 nm of UV-VIS (JASCO, UV-600). The amount of colloid deposited on the membrane was calculated using the follow,

$$\text{The amount of colloid deposited (mg)} = \sum_0^v (C_0 - C_i) v_i \quad (3)$$

where C_i is concentration of colloid dispersed in each fraction, C_0 is initial concentration of colloid dispersed in solution, and v_i is volume of each fraction.

Rejection of 100 nm Latex beads and Soy Insoluble Protein Through Latex-beads (1 μm)-Deposited Membrane

Latex beads (1 μm) were deposited on the pore of the membrane. And then latex beads (100 nm) dispersed solution was flown through Latex-beads (1 μm)-deposited membrane. The concentration of Latex beads (100 nm) was determined by 600 nm. From each obtained fraction, the rejection percentage was calculated as follow,

$$\text{Rejection (\%)} = (\text{conc. of latex beads (100 nm) in each fraction}) / (\text{initial conc. of Latex beads (100 nm)}) \quad (4)$$

Soy insoluble protein (FujiPro F) dispersed solution (25 mg/L, in pure water) was flown through the Latex-beads (1 μm)-deposited membrane. The flow rate of the solution was set at 25 mL/h. The effluent flown from the membrane was collected to each fraction. The concentration of insoluble protein in the effluent was determined by 440 nm of UV-Vis. The concentration of soluble protein was determined by Bradford method (Bradford, 1976).

Results And Discussion

Latex-beads (1 μm) Deposition on the Membrane Pore

Pressure change in permeating Latex beads (1 μm)

solution through the trunk membrane, porous hollow-fiber membrane, for deposition is shown in Figure 2. Pressure loss increases straightly in increasing feed time. Latex deposition on the membrane increases the pressure loss in permeating solution because the deposited layer will be the resistance for the permeation. The filtration phenomena using the microfiltration and ultrafiltration can be considered as following classification, 1) cake filtration, 2) intermediate blocking, 3) standard blocking, and 4) complete blocking. Filtration rate equation is expressed as the follow,

$$dp/dv = k_n p^n \quad (5)$$

where p , v , k , and n are pressure loss, filtration volume, resistance coefficient, and blocking index, respectively. The values of blocking index such as 0, 1.0, 1.5, and 2.0 represents 1) cake filtration, 2) intermediate blocking, 3) standard blocking, and 4) complete blocking, respectively. The slope in Figure 2 was calculated to be zero, demonstrating that the filtration of Latex beads ($1\ \mu\text{m}$) was cake filtration, that is to say, all the Latex beads ($1\ \mu\text{m}$) were perfectly deposited on the pore ($360\ \text{nm}$) of the porous hollow-fiber membrane.

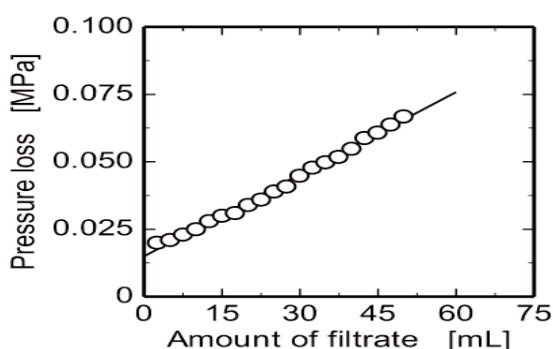


FIG. 2 FILTRATION OF LATEX BEADS THROUGH THE POROUS HOLLOW-FIBER MEMBRANE TO CONSIDER THE BLOCKING MODEL

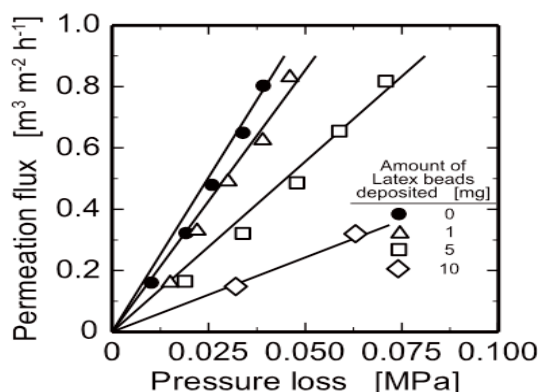


FIG. 3 PERMEATION FLUX AS A FUNCTION OF PRESSURE LOSS IN CHANGING THE AMOUNT OF LATEX BEADS DEPOSITED
Permeation flux in changing the deposited amount of

Latex beads ($1\ \mu\text{m}$) from 0 mg to 10 mg is shown in Figure 3. The more the amount of Latex beads ($1\ \mu\text{m}$) deposited, the more the slope between pressure loss and permeation flux, because of the increment of fluid resistance, that is, cake resistance.

The pressure loss of the membrane was changed due to the formation of cake layer on the pore. The over-all pressure loss of the membrane was possibly calculated using the following equation,

$$F = p / [\eta_0 (R_m + R_c)] \quad (6)$$

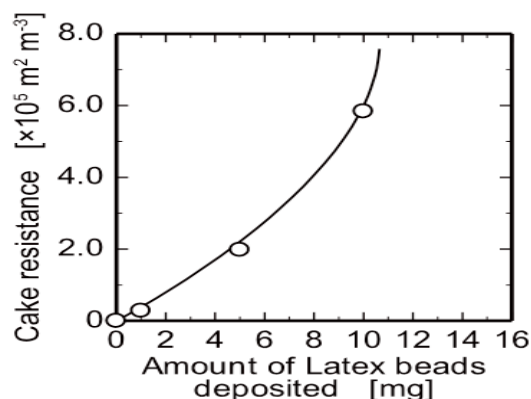


FIG. 4 CAKE RESISTANCE OF LATEX BEADS DEPOSITED ON THE MEMBRANE

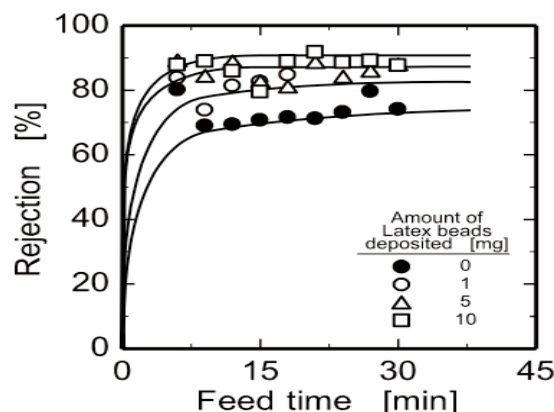


FIG. 5 REJECTION PERCENTAGE OF LATEX BEADS (100 NM) THROUGH THE LATEX-BEADS (1 μm) DEPOSITED MEMBRANE

where F , p , η_0 , R_m and R_c are permeation flux, pressure loss, viscosity of fluid, resistance of supported membrane, and resistance of cake layer, respectively. Calculated R_c in changing the amount of Latex beads ($1\ \mu\text{m}$) deposited is shown in Figure 4. With increasing the amount of Latex beads ($1\ \mu\text{m}$) deposited, the cake resistance exponentially increased. When the deposited structure of Latex beads ($1\ \mu\text{m}$) on the membrane is constant in the depth, the cake resistance comes to constant. In this study, because the cake resistance exponentially increases, the cake layer gradually comes to be at high density.

Evaluation of Latex-beads (1 μm) Deposition Structure on the Membrane in Permeating Colloidal Particle

The filtration performance of Latex-beads (1 μm)-deposited membrane was evaluated. Latex beads (100 nm)-containing solution was flown through Latex-beads (1 μm)-deposited membrane to evaluate the rejection performance (Figure 5). With permeating the colloidal Latex beads (100 nm) solution, the rejection percentage of Latex beads (100 nm) increased because the rejected Latex beads (100 nm) was deposited as a skin layer and filtered the colloidal particle by themselves. With increasing the amount of Latex beads (1 μm) deposited, the rejection percentage of Latex beads (100 nm) gradually increased.

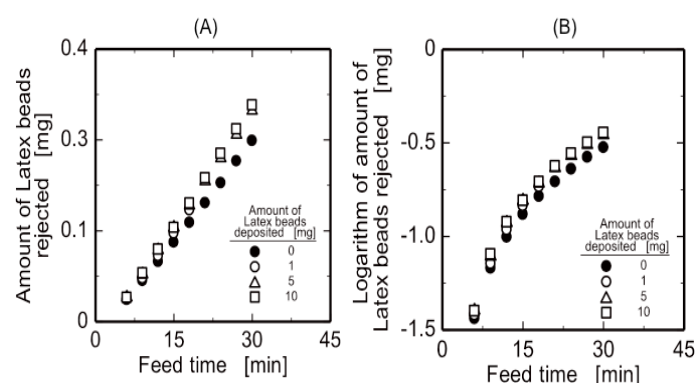


FIG. 6 (A) THE AMOUNT OF LATEX BEADS REJECTED THROUGH THE LATEX-BEADS-DEPOSITED MEMBRANE AND (B) RECALCULATION OF (A) FOR REJECTION COEFFICIENT

The rejection percentage of Latex beads (100 nm) was recalculated to determine the amount of Latex-beads (100 nm). The amount of Latex beads (100 nm) as a function of feed time is shown in Figure 6 (a). The amount of Latex beads (100 nm) rejected was dependent on the amount of Latex beads (1 μm) on the membrane. The amount of Latex beads (100 nm) rejected was changed to logarithm and obtained in

Figure 6 (b) using the following equation,

$$\log(\text{amount of latex beads (100 nm) rejected}) = kt + C \quad (7)$$

where k , t , and C are rejection coefficient, time, and integral coefficient, respectively.

To determine the initial state of the filtration, k , rejection coefficient, was calculated using the initial period to fit the straight line. The relationship between rejection coefficient, k , and the amount of Latex beads (1 μm) is shown in Figure 7. With increasing the amount of Latex beads (1 μm) deposited, the rejection coefficient gradually increased, demonstrating that the

increment of Latex beads (1 μm) deposited on the membrane enhanced the filtration performance due to the high-density structure, as discussed in previous section.

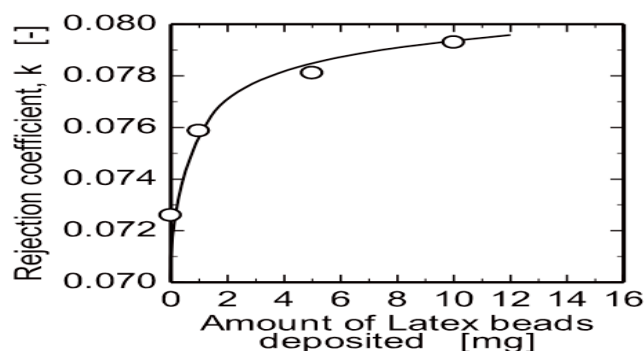


FIG. 7 REJECTION COEFFICIENT VS AMOUNT OF LATEX BEADS DEPOSITED

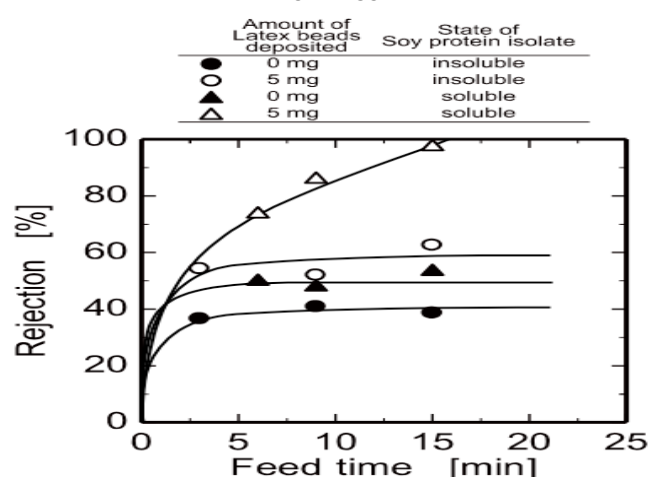


FIG. 8 REJECTION PERCENTAGE OF SOY INSOLUBLE PROTEIN THROUGH THE LATEX-BEADS DEPOSITED MEMBRANE

As shown in Figs. 5 and 8, the pore size of over-all membrane became more smaller than 360 nm of unmodified membrane, because the rejection percentage increased due to formation of the latex beads layer on the membrane. Calculation of pore size of the latex-beads layer formed on the membrane is difficult, because the height of latex-beads layer is hardly observed due to the problem such as unstable structure of the layer. However, as shown in Figs. 5 and 8, latex-beads deposition increased the rejection percentage to predict narrowing the pore of the over-all membrane compared with unmodified membrane. Using the height of latex-beads layer, the calculation of the pore diameter is possible by Hagen-Poiseuille equation. Observation of the height of the deposited latex beads is possible if the deposited layer is maintained by lyophilization on the membrane. As a result, the pore size of latex-beads layer is may-be calculated by the observed height of the deposited layer.

Filtration of Soy Insoluble Protein Using Latex-beads (1 μ m)-Deposited Membrane

Soy insoluble protein is used in food and medical materials. To extract some compounds is crucial in the view of engineering. In this study, the solution dispersed with soy insoluble protein was flown through the Latex-beads (1 μ m)-deposited membrane. Concentration of soluble and insoluble proteins in the effluent was analyzed as a function of feed time shown in Figure 8. Trunk membrane represented the filtration of the small amount of soluble and insoluble proteins. Latex-beads (1 μ m)-deposited membrane filtered insoluble protein more than trunk membrane due to sieving effect. During the filtration of Latex beads (100 nm), the soluble protein was adsorbed to the deposited layer of Latex beads (1 μ m) and filtered Latex beads (100 nm). Therefore, the Latex-beads (1 μ m)-deposited membrane not only filtered he insoluble soy insoluble protein, but also adsorbed the soluble protein. This kind of colloid-deposition on the membrane would play an important role in food engineering for sophisticated separation.

Conclusions

One micrometer of Latex beads was deposited on the porous hollow-fiber membrane in permeation mode for the novel filtration performance of colloidal particle, especially for food engineering. The amount of Latex beads (1 μ m) deposited on the membrane was changed because the structure of the deposited layer came to the higher density. Soy insoluble protein solution was filtered using Latex-beads (1 μ m)-deposited membrane, demonstrating that deposited cake layer functions for the filtration and adsorption of the insoluble and soluble proteins. This is one of fascinated technique for the separation of colloidal particle in food engineering.

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